Energy Resolution in GERDA's Phase I

Francis Froborg

University of Zurich

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University of Zurich[UZH]

GERDA

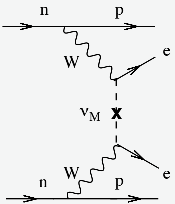
Overview

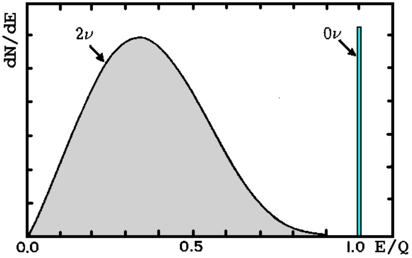
1. Motivation
2. How to get information about the energy resolution?
   - The Calibration System
3. How to optimize the energy resolution?
   - Signal Processing
4. Summary

Neutrinoless Double Beta Decay

$0\nu\beta\beta$

- $(Z, A) \rightarrow (Z+2, A) + 2e^-$
- $\Delta L = 2$
- $\left|T^{0\nu}_{1/2}\right|^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2\,\langle m^2_{\beta\beta}\rangle \sim \left|10^{25}\text{ y}\right|^{-1}$
- $\langle m_{\beta\beta}\rangle = \left|\sum_i U^2_{ei}\, m_i\right|$





The Experimental Challenge

Sensitivity

$$T^{0\nu}_{1/2} \propto \langle m_{\beta\beta}\rangle^{-2} \propto const \sqrt{\frac{M \times t}{\Delta E \times B}}$$

- M Mass
- t Time
- B Background rate
- ΔE Energy resolution

Maneschg, Merle, Rodejohan, arXiv:0812.0479v1

The GERmanium Detector Array (GERDA)

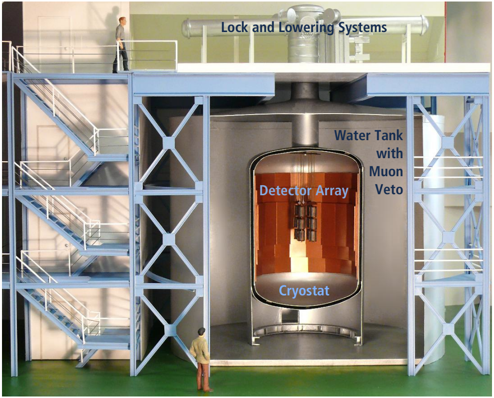
Naked High purity ^{76}Ge crystals placed in LAr

Phase I goals

Exposure	15 kg y
Background	10^{-2} cts/(keV kg y)
Half-life	$T_{1/2} > 2.2 \times 10^{25}$ y
Majorana mass	$m_{ee} < 0.27$ eV

Phase II goals

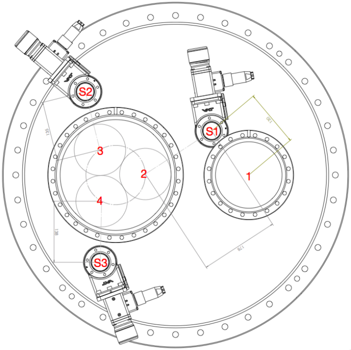
Exposure	100 kg y
Background	10^{-3} cts/(keV kg y)
Half-life	$T_{1/2} > 15 \times 10^{25}$ y
Majorana mass	$m_{ee} < 0.11$ eV



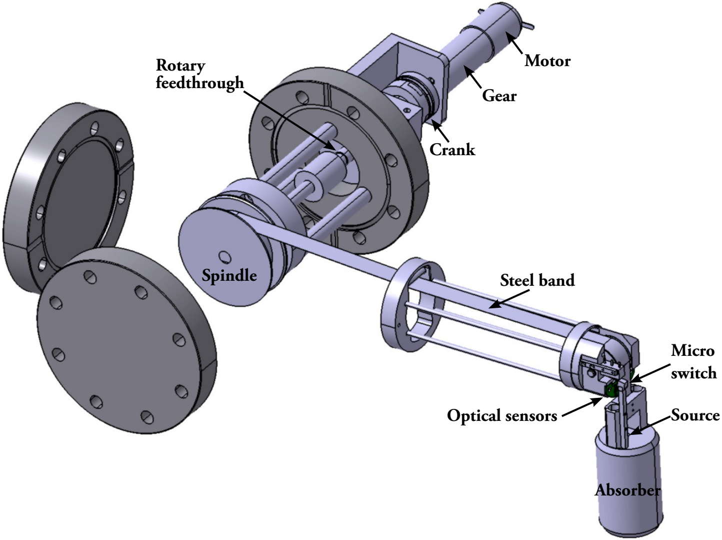
Calibrations
Overview

Overview

- 4 strings with 3 detectors each
- 3 ^{228}Th sources with $A = 10 - 15$ kBq
- Park position in the lock of the experiment
- Sources shielded by 6 cm of Ta
- 1 Calibration run per week:
  - 2 different z positions
  - $\sim$ 30 min run time per position



The Calibration System



Positioning Systems

Absolute Encoder

- Measures rotation of spindle
- Correctly calibrated, it gives the absolute position even in case of a power shut down
- Accuracy depends on reproducibility of winding of steel band

Incremental Encoder

- Two optical sensors (reflection light barriers) count holes in perforated steel band
- Chronology of impulses of sensors define forward and backward direction
- Accuracy depends on distance of holes and sensors and accuracy of perforation

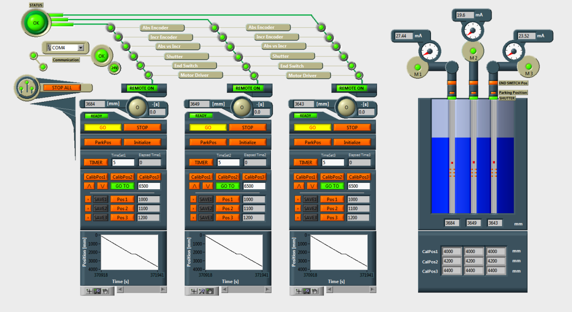
Controller

System Control Unit

Firmware with 3 functional blocks per lowering system:
Motor, positioning and error control

Remote Control

LabView Program to operate and monitor all 3 lowering systems

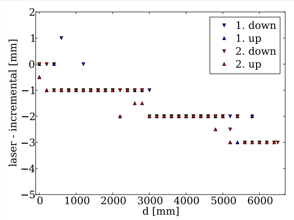


PhD Thesis by Michal Tarka

Positioning Tests

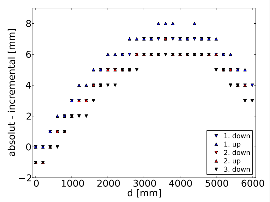
Incremental Encoder vs. Laser Rangefinder

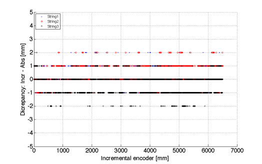
- Sources moved down to 6.5 m in 0.2 m steps
- Tolerable discrepancies of up to 3 mm found



Incremental vs. Absolute Encoder

- Every system showed different deviation
- Discrepancy of up to 15 mm
- Calibration function for each system implemented
- Accuracy after calibration ±2 mm





Other Tests

Oscillation Tests

- During movements: Oscillations < 5 mm and rotations 25-30° well below limits
- Entering LAr: Oscillations and rotations enhances by factor of 2 due to boiling
  $\Rightarrow$ Fixed stop position at LAr level

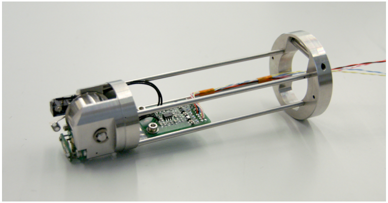
Error Handling

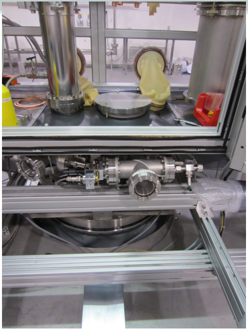
Malfunction of each subsystem, blockade of source and possible combinations tested successfully

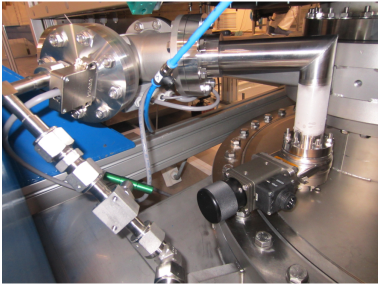
Long Term Stability

About 50 cycles down to 6.5 m and up without any incidents

Some Pictures

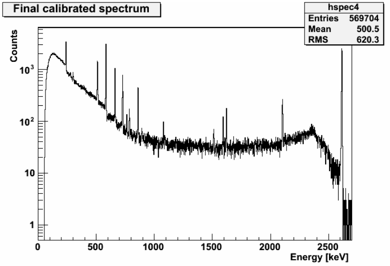


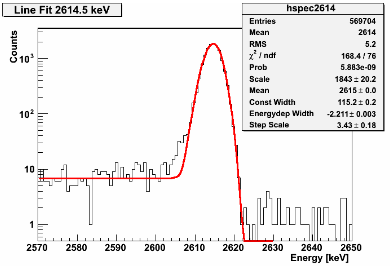




The Calibration Spectrum

Status

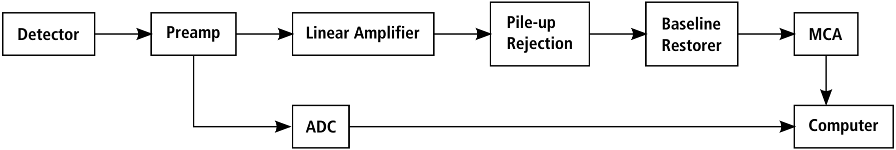




- Phase I: Closed-ended coaxial Ge diodes, p-type
- First string with three natural Ge detectors deployed in June 2010
- First string with enriched detectors deployed in June 2011
- Energy resolution (FWHM@2.6 MeV): 3.6 keV to $\sim$ 5 keV

Optimization of Energy Resolution

Signal Processing Chain

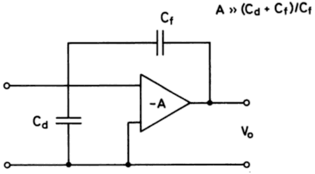


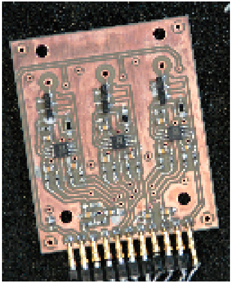
Preamplifier

- Charge-sensitive preamp integrates incoming pulse
- Charge stored on capacitor C_f
- Charge removed from C_f via resistance feedback network with characteristic time scale

$$\tau_{\text{preamp}} \equiv RC_f$$

- τ_{preamp} has to balance ballistic deficit and pile-up rate



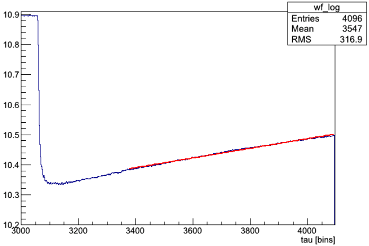


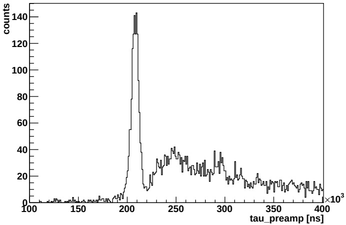
Determination of Decay Time

- Fit exponential tail of pulse
- Generate histogram with fit results
- Separate for each detector
- Use peak value for further analysis

Preliminary Result

$$\tau_{\text{preamp}} \simeq 170 - 210\,\mu\text{s}$$

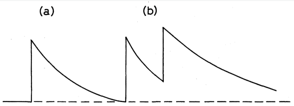




Amplitude Distortions

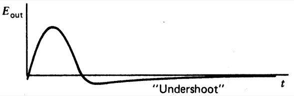
Pile-up

- Decay time longer than time between two events



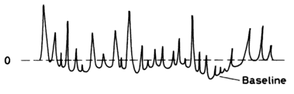
Undershoot

- Output of preamp is not a step function but has a long but finite tale
- Respond of shaping network is an undershoot



Baseline Shift

- High event rates lead to a shift of the baseline below its true zero



Baseline

Baseline Restoration

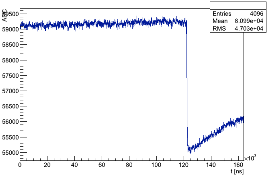
- Fit at baseline: base $= a + b \cdot exp(-t/\tau_{\text{pa}})$
- Fit window has to be larger than decay time
- Subtract fit result from pulse

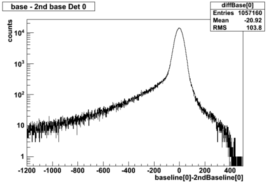
Pile-up rejection

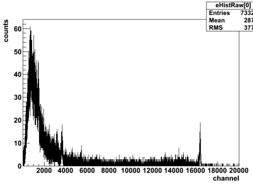
- Choose two windows:
  1. At beginning of recorded pulse
  2. Just before trigger
- Cut, if difference is too large

Noise

- Cut, if baseline spread is too large in chosen window







Signal Shaping

Gauss

Analog

- CR-(RC)^n network
- Usually $n = 4$ sufficient
- Equal time constants for differentiation and integration networks

Digital

- Moving Window Deconvolution (MWD) + 2× Moving Window Average (MWA)
- MWD = Differentiation + Pole Zero Cancellation
- MWA = Integration
- All window sizes the same

Advantage

Noise reduction due to frequency filtering

Disadvantage

Small amplitude differences due to rise time changes

Signal Shaping

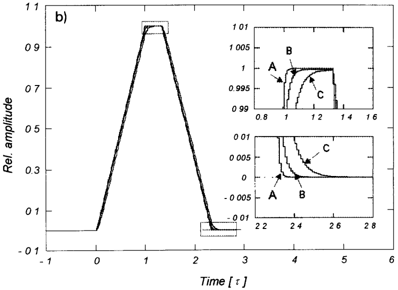
Gast

Advantage

- Invariant to rise time changes resulting in ballistic deficit

Digital Realization

- MWD + MWA
- Window MWD > Window MWA
- Free parameter determines position at flat top where amplitude



Jordanov and Knoll, 1994

Summary and Outlook

- GERDA started commissioning phase in June 2010
- First enriched detectors deployed in June 2011, rest will follow in Sep 2011
- Calibration system is working properly
- Optimization of offline pulse processing to improve energy resolution in progress